MODEL REFERENCE ADAPTIVE CONTROL FOR ONE DOF HAND REHABILITATION ROBOT

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For love of my life's

En. Mazlan bin Majid and Pn. Azlimah binti Fakir

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ABSTRACT

This project presents one type of adaptive control technique to control the position of Direct Current (DC) motor for one-DOF rehabilitation robot. A DC motor is generally act as actuator in one-DOF rehabilitation robot and usually the robots are developed without gearing or reducer to make them drivable and can give easiness to stroke patients. Besides that, DC motor has variations in its parameters during operation and it also sensitive to disturbances, presence load and environment. Therefore, it may require an advance technique to make the DC motor position stable. Many different types of controllers were used to provide the accurate positioning of DC motor of one degree of freedom (DoF) rehabilitation robot. One of them is Proportional Integral Derivative (PID) controller. Even though PID controller is simple, stable and easy adjustment, but it not be able to adapt the variation load of stroke patient handgrip stiffness and it can only tune for each standard stiffness only. Therefore, this project will designed and develop the Model Reference Adaptive Control (MRAC) using one of adaptive mechanism that is Lyapunov Method. The MRAC with Lyapunov method is used in order to obtain good controller for position control of DC motor and able to cope with variations handgrip stiffness of stroke patients using one-DoF rehabilitation robot. Besides that, while using the MRAC there will be the uncertainties such as parameter drift and in order to cope with these uncertainties and have robust MRAC, this system required a robust modification such as sigma modification and e-modification. In this project, the comparison between MRAC using Lyapunov method, MRAC with sigma modification and MRAC with e- modification being examined. As conclusion, simulated results show that 90% of the sigma modification will reduce steady state error, system stable and can reduce settling time rather than using MRAC using Lyapunov method and MRAC with e-modification. So, MRAC with sigma modification is the good type of MRAC for controlling the position of DC motor in one-DoF rehabilitation robot where the stroke patients can train their hand in good way.

ABSTRAK

Projek ini membentangkan satu jenis teknik kawalan penyesuaian untuk mengawal kedudukan motor DC untuk robot pemulihan satu DoF. Motor DC biasanya bertindak sebagai penggerak dalam robot pemulihan satu-DOF dan biasanya robot-robot itu berkembang tanpa gearing atau reducer untuk menjadikannya mudah dikendalikan, dan memudahkan pesakit angin ahmar. Oleh kerana, motor DC mempunyai variasi parameter semasa operasi dan ia juga sensitif terhadap gangguan, beban kehadiran dan persekitaran, oleh itu, ia memerlukan teknik canggih untuk menjadikan kedudukan motor DC stabil. Banyak jenis pengawal yang digunakan untuk memberikan kedudukan yang tepat bagi motor DC satu robot pemulihan DoF. Salah satunya ialah pengawal PID. Walaupun pengawal PID adalah penyesuaian mudah, stabil dan mudah, namun ia tidak dapat menyesuaikan beban variasi kekejangan handgrip pesakit strok dan ia hanya boleh menyesuaikan untuk setiap kekakuan piawai. Oleh itu, projek ini akan membangun dan merekabentuk Kawalan Penyesuaian Rujukan Model (MRAC) menggunakan salah satu mekanisme penyesuaian iaitu Kaedah Lyapunov untuk mendapatkan pengawal yang mantap untuk mengawal kedudukan motor DC dan dapat mengatasi variasi kekejangan handgrip pesakit strok menggunakan satu-DoF robot. Selain itu, semasa menggunakan Kawalan Penyesuaian Rujukan Model (MRAC) akan ada ketidakpastian seperti hanyutan parameter dan untuk mengatasi ketidakpastian ini dan mempunyai MRAC yang mantap, sistem ini memerlukan pengubahsuaian yang mantap seperti pengubahsuaian sigma dan pengubahsuaian. Dalam projek ini, perbandingan antara MRAC menggunakan kaedah Lyapunov, MRAC dengan pengubahsuaian sigma dan MRAC dengan pengubahsuaian elektronik yang diperiksa. Sebagai kesimpulan, hasil simulasi menunjukkan bahawa 90% pengubahsuaian sigma akan mengurangkan kesilapan keadaan mantap, sistem stabil dan boleh mengurangkan masa penyelesaian daripada menggunakan MRAC menggunakan kaedah Lyapunov dan MRAC dengan pengubahsuaian.

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LIST OF SYMBOLS AND ABBREVIATIONS

K_t	–	Torque constant
K_b	–	Back emf constant
H	–	Inductance
J	–	Moment of Inertia
R	–	Resistance
I_c	–	Max current
K_i	–	Integral gain
K_d	–	Derivative gain
e	–	Error
θ_1, θ_2	–	Control parameters
K_p	–	Proportional gain
b	–	Viscous friction constant
r	–	Input signal
γ	–	Adjustment gain
y_m	–	Reference model output
y	–	Actual plant output
u	–	Controller
σ	–	Sigma
m	–	Coefficient of m
n	–	Coefficient of n

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Stroke is one of the sicknesses that may reason for death and it conjointly state as a significant public pathological state in worldwide. Based on the Global Burden of Diseases, Injuries and Risk Factors Study (GBD) in 2016, stroke was compete because the second common reason for death and therefore the third most typical of incapacity adjusted life years (DALYs) [1]. Stroke will have an effect on all cohorts from time of life to old folks with rising in ages. The life time risk for stroke patients may be nearer to 100% to death. Next, stroke also affect either men or women equally that can burden the society [2].

In Malaysia, stroke place as third place reason for death when cancer and heart failure that kill additional with greatest burden of illness and one in every of prime 10 cause for hospitalization in Malaysia [3]. Statistics in Malaysia state that high blood pressure could be a major risk issue for stroke that play concerning (53.2% to 76.1%) continue with diabetes (27.4% to 55.2%) and smoking (19.4% to 37.3%) and stroke patients largely attack Malay that plays highest rank 66.1%, Chinese 25.0%, Indians 5% and different races 1.4% [3]. The range age of stroke patients are between 50 years until 63 years largely attack man over women customary prescription is sometimes rehearsed. With the increasing range of stroke cases once a year, bigger government and nongovernment associations got to be engaged with essential and auxiliary offsetting action techniques [3]. Based on Figure 1.1, Stroke Mortality in association countries, stroke kills 3,128 individuals annually in Asian country and Malaysia's crude death rate for stroke was 15.9 for each 100 000, that is under Philippines, Singapore, Negara Brunei Darussalam and Thailand [7].

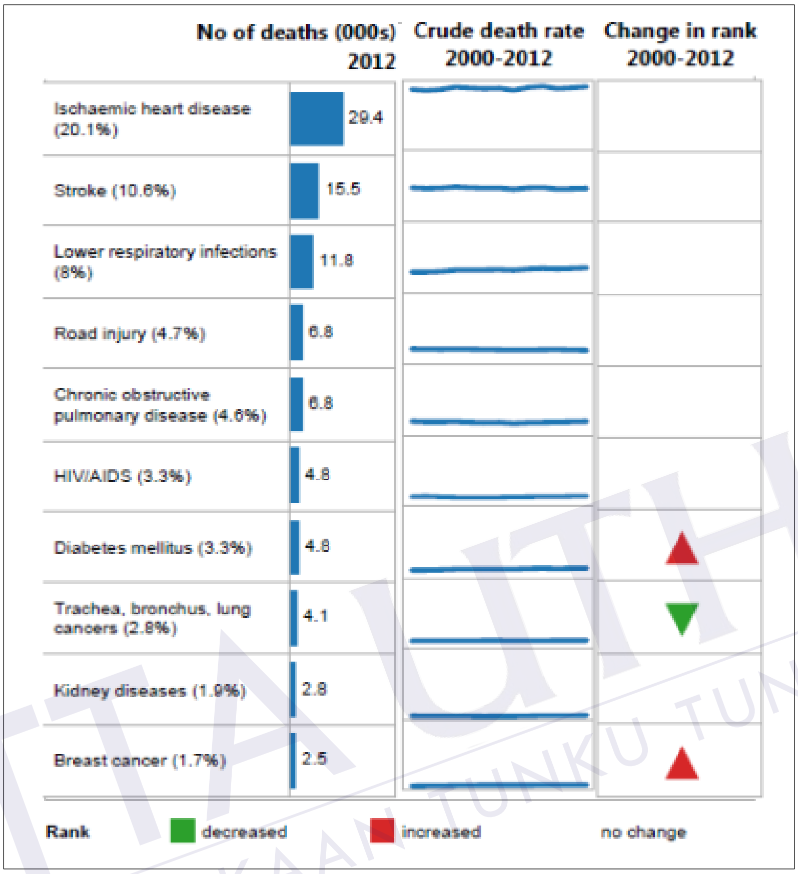


Figure 1.1: Stroke Mortality in ASEAN countries.

Stroke is a brain attack which will happen to anyone at any time. It happens once blood flow to a vicinity of brain is cut-off and once this happen, brains cells are deprived of oxygen and start to die. The stroke patients are going to be ineffective to moving, walking or thinking once stroke happen [4]. Stroke may be divided into 2 sort which are ischemic stroke that caused by blockage of blood supply to brain and haemorrhagic stroke that caused by bleeding in or round the brain. Once somebody got the stroke, it will affect not just your body but also about how you think, feel and communicate [5]. The Figure 1.2 and Figure 1.3 show two types of strokes.

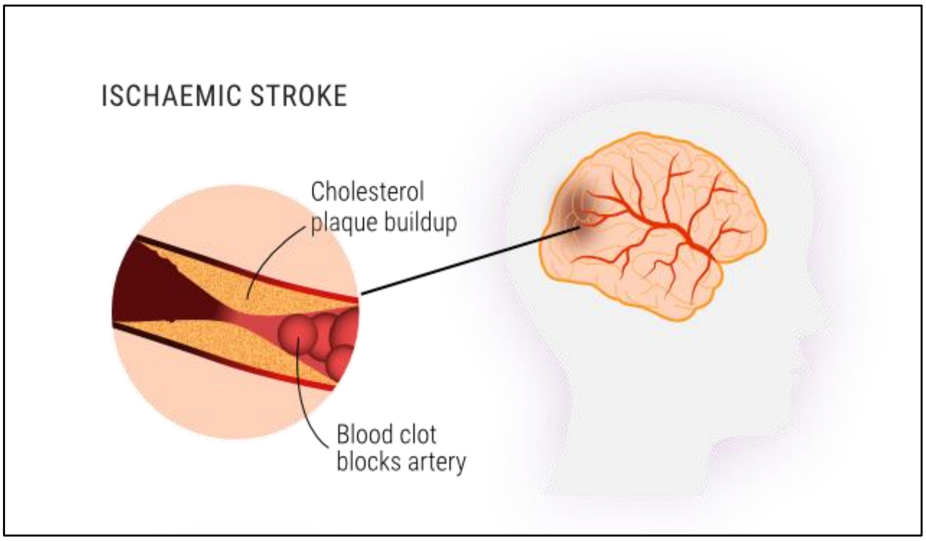


Figure 1.2: Ischemic Stroke [5].

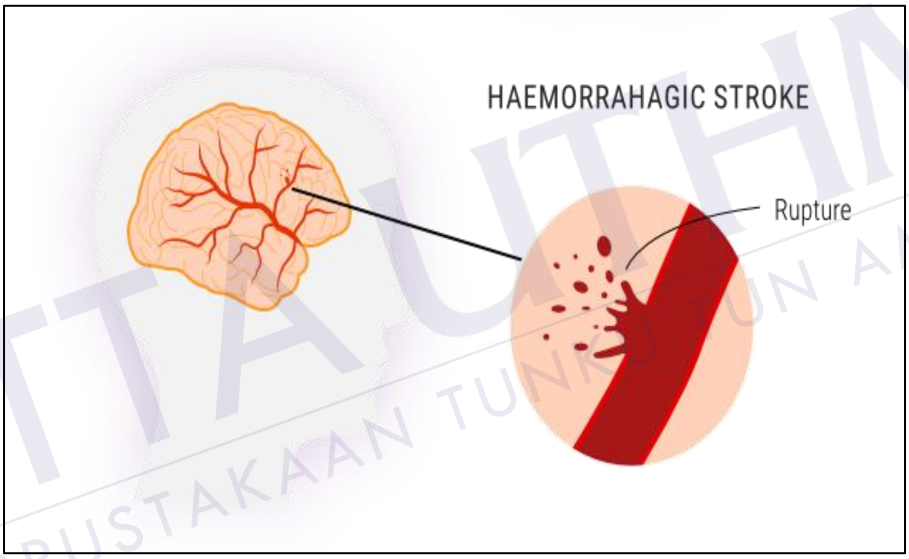


Figure 1.3: Hemorrhagic Stroke [5].

1.2.2 Occupational Therapy

For Occupational Therapy, they are focusing on improving stroke patients' ability to perform daily life such as bathing, eating and dressing more effectively. Next, from this Occupational Therapy, they also help to improve the self-confidence of stroke patients.

Figure 1.5: Occupational Therapy

1.2.3 Other Alternatives

Alternatives for stroke recovery care can be classified dependent in 3 general purpose which are hospital, community and institution. Firstly, in hospital there are provided the recovery treatment to the outpatients' stroke and inpatients stroke. The outpatient stroke will come to the hospital to get some advice and will do some treatments while for inpatients stroke, they got special advantages where they do their treatment in longer time by the Physiotherapist. Basically, at the hospital the outpatients stroke and inpatients stroke are doing a treatments like learn how to walk, eat and etc. Secondly, Institutional stroke rehabilitation cares. This institution was given a nursing homes or homes for the old and network stroke restoration care, which is typically given by a group of Physiotherapists and Occupational Therapist [10]. Lastly, in community. All communities plays important figures in order to give the moral support to the stroke patients, where they can help the stroke patients in many ways such as help to increase the self-motivates of stroke patients to always positive and never give up in life.

Nowadays, there are many of application of rehabilitation robot increasing rapidly and become high demand in industry due to this robot can provide good rehabilitation for a longer time to stroke patients. One of them is one-DOF rehabilitation robot. This robot is simple and eco-friendly where it solely worn by stroke patients to train their hand continuously in longer time and can be used at home without the aid of therapist because it is built without drivable gear. The Figure 1.6 shows CR2-Haptic Robot that may be accustomed train stroke patient hand that is one-DoF rehabilitation robot that may be accustomed train radiocarpal joint and forearm movement. The robot allows the patient to coach their muscle perform whereas enjoying the computer games provided within the display.

Figure 1.6 : CR2-Haptic robot

Besides that, to control the movement of one-DoF rehabilitation robot, it needs accurate position of DC motor so that one-DoF rehabilitation robot can guide the hand of stroke patients in variety range of stiffness and adapt variations in the load.

In this project, one of the adaptive controls was being introduced to control the position of DC motor. It is MRAC. The MRAC can control the position of DC motor that has variation in parameters during operation system and DC motor also sensitive to load variety of load. There are two main types of MRAC designed method can be used like Lyapunov method and Gradient method but for this project, MRAC with Lyapunov method is being used due to the closed-loop system that being obtained is always stable. Besides that, while using the MRAC there will be the uncertainties such as parameter drift and in order to cope with this problem and have robust

MRAC, this system required a robust modification such as sigma modification and e-modification.

1.3 Problem Statement

Nowadays, one-DoF rehabilitation robot got a high demand in medical industry and becoming a top of robot that being used due to it can provide intensive rehabilitation to stroke patients especially for their hands [6]. Next, one-DoF rehabilitation robot also become popular because it is the simplest robot and affordable so that the stroke patients can buy and use it at home without the help from therapist. One-DoF rehabilitation robot was built without gearing or reducer to make them back drivable, therefore the rehabilitation robot movement were control by the DC motor generally.

Position of DC motor become attractive part within one-DoF rehabilitation robot. Many varieties of controller getting used to manage the position of DC motor. One of them is PID. PID controller is straightforward, stable and high responsibility however it cannot handle variations of DC motor parameters and it can solely tune for its own standard stiffness wherever it will offer the unhealthy impact to stroke patients that require exercising their hand in variation angle and stiffness.

Next, MRAC with Lyapunov method is one of adaptive control techniques for manage the position of DC motor that handle variations of stiffness parameters. MRAC will regulate itself to variation parameter and can force the actual plant output to follow the reference model. In order to address the uncertainties in MRAC, this system needed a modification in adaptive low to create MRAC more robust.

1.4 Objectives

The objectives of the project are:

i. To develop a mathematical model of DC motor with the suitable assumption of the stroke patient hand.

ii. To design the PID controller, MRAC with Lyapunov method , MRAC with Sigma Modification, and MRAC with e- Modification for one-DoF rehabilitation robot.

iii. To evaluate the performance between the PID Controller, MRAC with Lyapunov method, MRAC with Sigma modification, and MRAC with e- Modification.

1.5 Scopes

The scopes of the project are:

i. This project only cover for simulation and the result simulation using MATLAB software Simulink.

ii. One-DOF rehabilitation robots only focus on handgrip stiffness of stroke patients.

iii. MRAC act as controller part and only focus on Lyapunov method.

iv. The projects only focus on two robust modifications which are sigma modification and e-modification.

v. The handgrip stiffness that used for this project are 0.4 and 0.6 Nm/rad.

vi. The PID controller, adjustment mechanism, and sigma, are tune manually by trial and error until get the desired output response.

CHAPTER 2

LITERATURE REVIEW

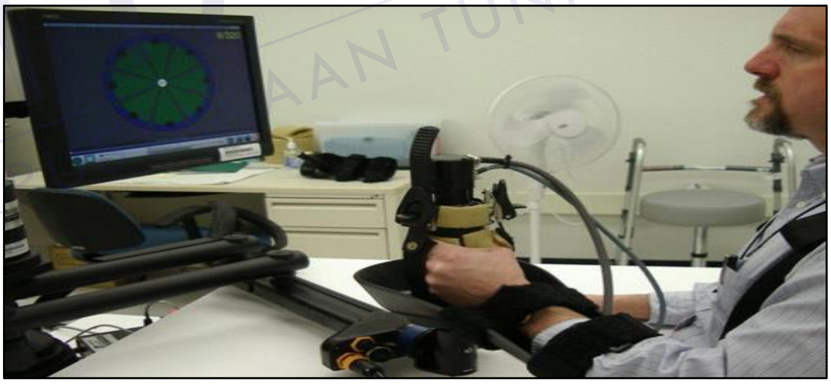
2.1 Hand Rehabilitation robot

The number of therapeutic rehabilitation robot has expanded dramatically during last twenty years ago and research into rehabilitation robot has grown rapidly year by year rapidly due to industry requirement. A robot is expressed as a re-programmable, multi-functional manipulator designed to move material, parts, or particular devices through variable programmed motions to accomplish a project [11]. Rehabilitation robot therapy can deliver high intensity and high-dosage practice, making it effective for stroke patients. Next, one application of robot-assisted therapy is can help stroke patients training their disability part of body more frequent in longer duration [11].

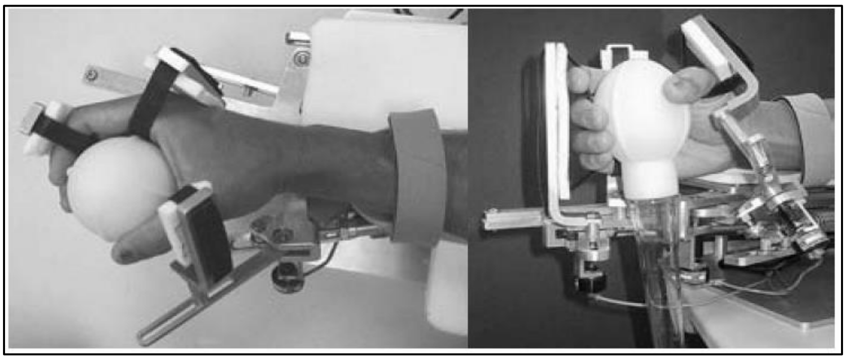
In this project, the hand rehabilitation robot being priority. Hand rehabilitation robot also call as robot-assisted therapy that facilitate the stroke patients to improve their hand function after a stroke syndrome. Hand rehabilitation robot can be classified in several DOF. So, if the amounts of DOF increase, the robot will become pricey and complex for hand rehabilitation robot, one DOF are more suitable because the robot simpler, affordable, and the stroke patient will be able to train their hand by itself.

Many examples of assistive robot were produced in the rehabilitation circle. Initial example of assistive robot is MIT-Manus. MIT-Manus is the robot that facilitate stroke patient handles a robotic joystick that controls their arm, wrist joint or hand as the patient attempts to make specific movements to move the limb on his or her own [12][7]. Moreover, stroke patients using the MIT-Manus system to grasp a joystick-like handle connected to a computer monitor that displays tasks similar to those in simple video games. In a typical task, the subject attempts to move the robot handle toward a moving or stationary target display on the computer monitor. If the person starts moving in the wrong direction or does not move, the robotic arm gently change his or her arm in the right direction [13]. Secondly, Hand-Wrist Assisting Robotic Device (HOWARD). HOWARD is a 3-degrees-of-freedom (3-DoF) mechanism that directly controls finger rotation about the metacarpophalangeal joint (MCP) [14] that allows the rotational movement of the fingers, thumb, and wrist and this robot that can teach the stroke patient grasp and release a variety of real object with varying shape, size and they will follow the movement based on purposeful instruction for example squeeze the toothpaste out [15].

Lastly, the assistive therapy robot is HEXORR. HEXORR is a robot that consist of two-DoF and it has two main modules which are finger module and thumb module [16][17]. The device acts as an exoskeleton so that the joints of the robot and the stroke patient hand are aligned throughout the allowed Random Open Memory (ROM). HEXORR uses a low-friction gear trains and electric motors [14]. Figure 2.1 shows the MIT-Manus Robot, Hand-Wrist Assisting Robotic Device (HOWARD) and HEXORR robot.



(a)



(b)

(c)

Figure 2.1: (a) MIT-Manus Robot and (b) HOWARD Robot (c) HEXORR robot

2.2 Types of Controller

2.2.1 Direct Current (DC) Motor

Direct Current (DC) motor is broadly utilised in industrial control application such as medical, aircraft, automation, compressor, electronic and etc. A DC motor is an electric motor that runs on coordinate current control. In any electric motor, operation is subordinate upon straightforward electromagnetism. A current carrying conductor produces an attractive field, when this is often then placed in an outside attractive field, it will experience a constrain corresponding to the current within the conductor and to the quality of the outside attractive field. The DC motors basically have two basic part which are rotating part and stationary part. The rotating part is called the rotor and stationary part called stator. The rotor rotates along with the stator. The rotor comprises of windings, the windings being electrically related with the commutator. The geometry of the brushes, commutator contacts and rotor windings are such that when control is connected, the polarities of the energized winding and the stator magnets are misaligned and the rotor will turn until it is exceptionally about rectified with the stator's field magnets. Next, as the rotor comes to arrangement, the brushes move to the following commutator contacts and energize another winding. The turn inverts the course of current through the rotor winding, inciting a flip of the rotor's attractive field, driving it to keep rotating. The Figure 2.2 shows the diagram of DC motor.

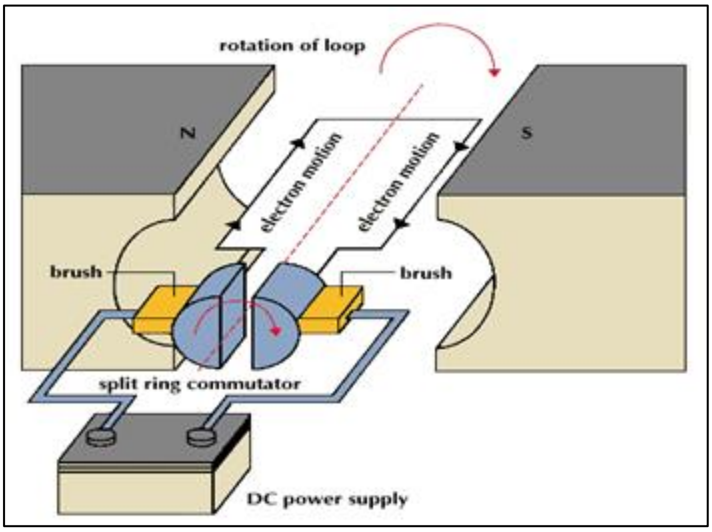


Figure 2.2: DC motor

The DC motor act as actuator in one-DoF hand rehabilitation robot where the one-DoF rehabilitation robot is developed without a gear or reducer to form it drivable. Within one-DoF rehabilitation robot there is a DC motor that control the position of rehabilitation robot, so there are many sorts of controller that being employed to regulate the position of DC motor so that the one-DoF rehabilitation robot will controlled variation stiffness of the stroke patients.

Junaid Zahid [6] developed an adaptive controller MRAC to control the position of DC motor in one-DoF rehabilitation robot. He reported that the PID controller were not be able to adapt variation parameters in the load and it have the limitation where can only tune for standard stiffness only. Then, the MRAC was introduce based on it capable to cover the wide area of the stiffness variation for stroke patients and can reduce the positioning error, steady state error and make the robot become benefit to stroke patients.

Tawanda Mushiri [18] implemented Model Reference Adaptive Fuzzy Controller (MRAFC) and MRAC with PID controllers to solve the valve cases of disturbances and non-linearity due to failure in pressured environment, temperatures and also contributions by moisture and abrasive particles. The simulation result shows that MRAFC showed excellent tracking result compared to MRAC with PID controller where Fuzzy Logic Controller more robust and good noise rejection to changing the plant parameters ad the performance of transient response.

Priyank Jain [19] was designing of a controller for a second order system with MRAC using the Massachusetts Institute of Technology (MIT) rule because the

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